Acta Orthop. Belg., 2007, **73**, 772-777

ORIGINAL STUDY

Evaluation of cruciate and slot auxiliary screw head design modifications for extracting stripped screw heads

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Slotted and cruciate auxiliary screw head design modifications for "salvaging" a stripped hexagonal head screw were studied. Thirty screws were divided into 3 groups : Group 1 = control without modification, Group 2 = auxiliary cruciate design modification and Group 3 = auxiliary slot design modification. Screws were inserted into adhesive filled high-density synthetic bone tunnels using a hexagonal driver. Group 1 screws were removed using a hexagonal driver. Group 2 and group 3 screws were removed using drivers that matched their respective auxiliary design modifications. All group 1 and group 3 screws (100%) were effectively extracted. Three of 10 (30%) group 2 screws could not be effectively extracted. Group 2 screws displayed greater stripping and deformation than the other groups. The auxiliary slot design modification withstood comparable extraction torques as control screws without significant deformation. Screws with a cruciate design modification displayed more frequent failure, greater stripping and deformation.

Keywords : trauma ; fracture fixation ; open reduction ; internal fixation.

INTRODUCTION

The screw is the most commonly used implant by orthopaedic surgeons to achieve stable fracture fixation and bony union (*3*). Hexagonal screw heads have become the standard for most screws that are currently used in orthopaedic surgery because they require low axial pressure for insertion, and can withstand high insertional torques (*2*). Hexagonal screw head designs however also have a major disadvantage in that even slight angulation between the driver and the screw head results in an increased incidence of screw head stripping. Since a hexagonal driver actually imbeds into the screw head, even slight alterations from a perfectly perpendicular alignment can result in screw head stripping. Behring *et al* (*2*) reported that insertion and removal of bone screws with hexagonal sockets is hampered following only one slippage episode with an approximately 50% reduction in initial maximum torque. In studying the influence of screw head design and driver angulation on screw head stripping, Spencer *et al* (*8*) reported that the star screw head design that they evaluated tended to

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No benefits or funds were received in support of this study

strip with increasing torque as driver angulation increased.

When hexagonal screw head stripping occurs during screw removal it significantly decreases the orthopaedic surgeon's ability to remove the screw, even after only one screw head-driver stripping episode (2,4). Even though it is an infrequent complication, an incarcerated screw with a stripped head can lead to increased surgical time, decreased surgical case flow, operating suite logistical issues, and occasionally increased risk of complications such as infection as a direct result of the extended time period that the patient spends in the operating room with an open wound.

Due to the increased risk of complications caused by an incarcerated screw with a stripped head many techniques and tools have been developed to remedy the situation. Gruber *et al* (6) described the use of a male hexagonal screw head, which would facilitate removal with a cannulated trephine. Devices such as the "Broken Screw Removal Set" (Synthes, Paoli, PA), a screw head gripping vise grip, a conical reverse-cutting male threaded tap, trephine reamers, or high-speed burrs like the Midas Rex (Osteonics, Fort Worth, TX) have also been reported (9). Each of these methods of incarcerated screw extraction also has shortcomings, either in the time it would take to effectively extract the screw, or in the creation of metal shards.

Another possible solution to salvaging screws with stripped heads would be a screw head design modification derived from a screw removal technique that is commonly used in woodworking. Carpenters often remove an incarcerated screw with a stripped head by cutting an auxiliary slot into the head of the stripped screw with a small, high-speed rotary motorised hand tool called a dremel. The stripped screw is then removed by the auxiliary slot with a flat head screwdriver. Even though this technique can be effective, screw head modification with the dremel would also create metal fragments. Therefore this method of stripped screw removal would not be well tolerated intra-operatively.

Perhaps a screw head could be designed with both a primary and an auxiliary or back-up screw head-driver interface. If the primary screw head design, the hexagonal head, was stripped, the auxiliary design could be utilised for incarcerated screw removal. For this purpose we considered two potentially useful auxiliary screw head design modifications : 1. cruciate, and 2. slot. We hypothesised that either auxiliary screw head design modification should provide an effective means of screw extraction without greatly damaging or deforming the screw head. The purpose of this study was to compare these two auxiliary screw head design modifications to a standard hexagonal screw head design for their ability to resist stripping or deformation during extraction.

MATERIALS AND METHODS

Thirty self-tapping cortical screws (3.5 mm core diameter, 25 mm length) (Synthes, Paoli, PA, USA) were divided into three groups of 10 screws each. The three groups each had a hexagonal primary screw head design. The standard hexagonal control group (group 1) did not have an auxiliary screw head design modification. Group 2 had an auxiliary cruciate screw head design modification. Group 3 had an auxiliary slotted screw head design modification. All auxiliary screw head design modifications were created to a depth equal to the base of the hexagonal screw head socket (2 mm) (fig 1). All other screw characteristics including outer diameter, root diameter, thread angle, and pitch were consistent between study groups to control for their influence on fixation (1).

Thirty 2.5 mm diameter pilot holes were drilled into 30 pcf (0.48 g/cc) density solid rigid polyurethane foam synthetic bone blocks (Sawbones®, Pacific Research Laboratories, Vashon, WA, USA). Each hole was injected with 0.3 cc of all-purpose polyurethane adhesive (Gorilla Glue, Cincinnati, OH, USA) to ensure that an adequate extraction torque level could be obtained during screw removal, thereby simulating an incarcerated screw. All 30 screws were then inserted into the predrilled holes in a random order with a hexagonal driver. Insertion torque was measured with a standard torque gauge (Model# MGT-10Z, Mark-10 Corp., Copiague, NY, USA). Following screw insertion, 12 hours of adhesive curing time was allotted prior to extraction. Three different driver head attachments were used for screw extraction (fig 2). A hexagonal driver was used for group 1, a cruciate driver was used for group 2, and a standard slot driver was used for group 3. Each driver attachment was used to manually extract the 10 screws contained in

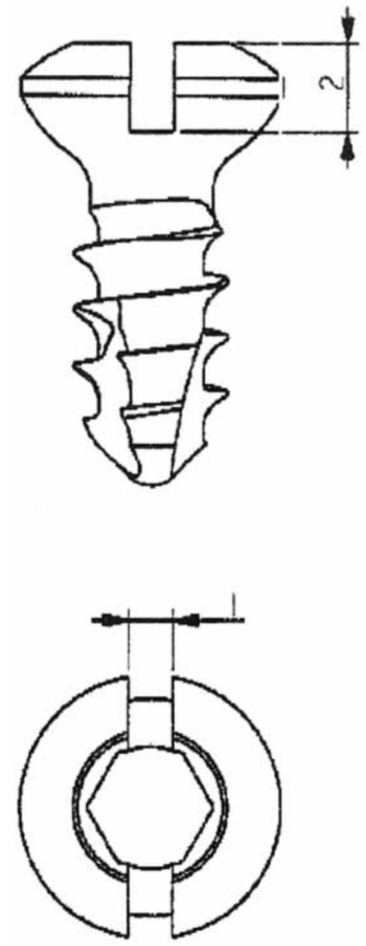

Fig. 1. — Screw head auxiliary slot dimensions (mm)

its respective group and the extraction torques of each screw was also recorded. The primary investigator performed all specimen preparation, screw insertions and extractions. Pilot testing revealed excellent intratester insertion and extraction torque measurement reliability ICC ≥ 0.91.

Following screw extraction an independent evaluator, who was blinded to the study hypothesis graded individual screw heads under 8 × magnification at a fixed distance of 3 cm from the lens. Screws were graded for : 1. stripping damage and 2. total screw head deformation. Ratings were performed of perceived screw head-driver interlocking interface integrity using a modified visual analog scale (VAS) with end range descriptors of 0 = severe stripping deformation or damage and 10 = no stripping deformation or damage.

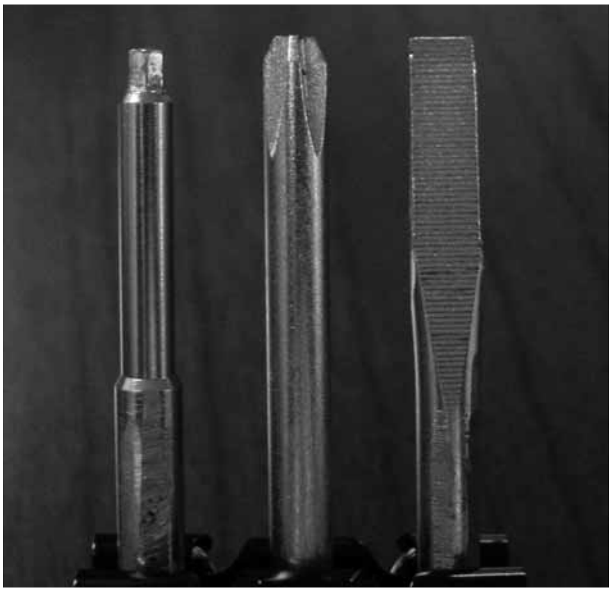

Fig. 2. — Drivers used for screw removal. From left to right : hexagonal, cruciate, and slot.

STATISTICAL METHODS

Kolmogorov-Smirnov tests revealed normally distributed data ; therefore parametric statistical analysis was used. A series of one-way ANOVA and Scheffe *post hoc* tests were used to evaluate group differences for insertion torque, extraction torque, screw head stripping damage, and total screw head deformation affecting screw head-driver interlocking. A Fisher's Exact Test was used to compare group extraction success frequencies. An alpha level of $p \leq 0.05$ was selected to indicate statistical significance. All statistical analysis was performed using SPSS version 11.0 for MS-Windows software (SPSS Inc., Chicago, IL, USA).

RESULTS

Group ANOVA results are reported in table I. Statistically significant differences were not observed for insertion torque ($p = 0.78$) or extraction torque ($p = 0.82$) (table II). However, 3 of 10 (30%) group 2 screws (auxiliary cruciate screw head design modification) could not be extracted using study methods. All group 1 (control, hexagonal screw head design without auxiliary modification)

Table I. — Descriptive insertion and extraction torque results by group

	Group	Mean	Standard Deviation	Standard Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Insertion Torque (in-lbs)	1	3.6	0.1	0.03	3.5	3.6	3.4	3.7
	2	3.6	0.1	0.03	3.5	3.6	3.4	3.8
	3	3.5	0.1	0.04	3.4	3.6	3.3	3.7
Extraction Torque (in-lbs)	1	27.1	1.9	0.64	25.6	28.6	24.9	30.2
	2	26.7	1.1	0.43	25.7	27.8	24.8	28.2
	3	26.8	0.7	0.21	26.3	27.3	25.7	27.9

Table II. — One-way ANOVA results for insertion and extraction torque by group

		Sum of Squares	df	Mean Square	F	P
Insertion Torque	Between Groups	0.01	2	0.003	0.26	0.78
	Within Groups	0.33	26	0.013		
	Total	0.33	28			
Extraction Torque	Between Groups	0.72	2	0.36	0.20	0.82
	Within Groups	41.57	23	1.81		
	Total	42.29	25			

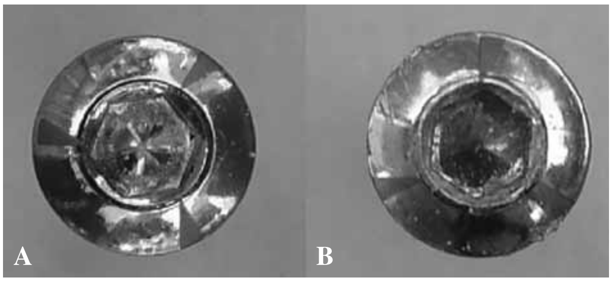

Fig. 3. — A. Hexagonal screw head. B. Typical hexagonal screw head following extraction.

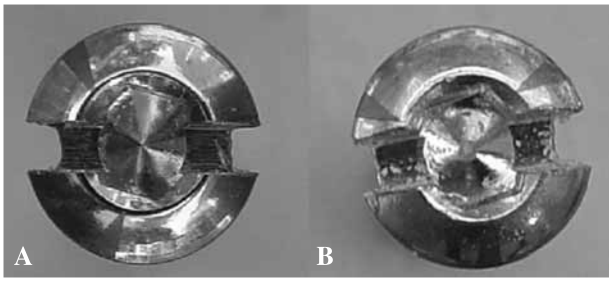

Fig. 4. — A. Auxiliary slot screw head design modification. B. Typical auxiliary slot screw head following extraction.

(fig 3A and 3B) and group 3 (auxiliary slot screw head design modification) (fig 4A and 4B) were extracted using study methods. The auxiliary cruciate screw head design modification group had a statistically significant greater frequency of failure during extraction (one-sided Fisher's Exact Test = 4.5, $p = 0.04$) (fig 5A and 5B). Descriptive modified VAS scores are reported in table III. Grading under magnification by an independent, blinded evaluator revealed that group 2 screws displayed significantly greater screw head-driver interface stripping than group 1 (6.0 ± 2.0 vs. 8.5 ± 0.7, $p = 0.001$) or group 3 (6.0 ± 2.0 vs. 7.9 ± 0.7, $p = 0.01$) screws. Group 2 screws also displayed greater screw head deformation than group 1 (6.0 ± 2.6 vs. 8.2 ± 0.8, $p = 0.017$) or group 3 (6.0 ± 2.6 vs. 7.8 ± 0.6, $p = 0.05$) screws. Groups 1 and 3 did not display statistically significant differences for either of these factors ($p > 0.60$). Moderate to severe deformation was noted in 30% of the cruci-

Table III. — Modified VAS score descriptive results by group

	Group	N	Mean	Standard Deviation	Standard Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Interface Stripping Damage	1	10	8.5	0.7	0.2	8.0	9.0	7.0	9.0
	2	10	6.0	2.0	0.6	4.6	7.4	3.0	8.0
	3	10	7.9	0.7	0.2	7.4	8.4	7.0	9.0
Screw Head Deformation	1	10	8.2	0.8	0.3	7.6	8.8	7.0	9.0
	2	10	6.0	2.6	0.8	4.2	7.8	2.0	8.0
	3	10	7.8	0.6	0.2	7.3	8.3	7.0	9.0

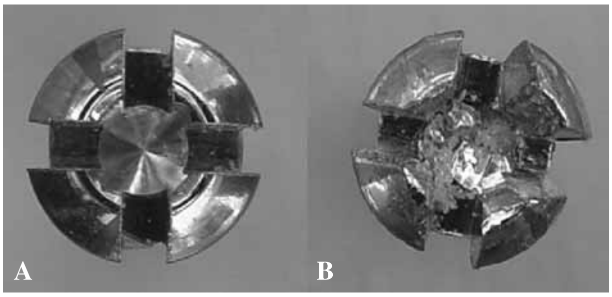

Fig. 5. — A. Auxiliary cruciate screw head design modification. B. Typical auxiliary cruciate screw head following extraction.

ate head screws, while no deformation or only slight deformation was noted in screws that had the auxiliary slot screw head design modifications or in the control group.

DISCUSSION

The torque values we observed for all successful screw extractions surpassed the recommended maximal strength for bone screws set by the International Organisation for Standards (*7*) suggesting adequate driver-screw head interface integrity. The auxiliary slotted screw head design modification enabled extraction without significantly deforming or weakening overall screw structural integrity. The auxiliary cruciate screw head design modification however failed to serve as an adequate means of auxiliary or back-up extraction, with 30% failing to be removed using experimental methods, and with significantly greater screw head-driver interface stripping and screw head deformation. As an auxiliary or back-up method of incarcerated screw removal the slot screw head design modification was clearly superior to the cruciate screw head design modification. When confronted with such a situation, surgeons in most cases have at their disposal a tapered cruciform screwdriver as reproduced by our study.

Several limitations are inherent in this study. The primary author who performed all biomechanical testing was not blinded to the screw group. Additionally, our test model did not include a fixation plate, thereby potentially decreasing the validity of our study results. Despite these limitations, we found the auxiliary cruciate screw head design modification to be inferior to the other test groups. Following creation of the auxiliary cruciate screw head design, four relatively small posts remain to absorb driver torque. This differs considerably from the tapered, well-centered interface between a standard Phillips screw head and its driver. By design the Phillips driver disengages if angulation with the screw head moves away from perpendicular to an angle where it is no longer well positioned for transferring torque to the screw shaft (*2*). This feature was not present in the auxiliary cruciate screw head design modification used in this study and likely caused excessive torque to be concentrated at the four screw head posts. However, if a specially designed non-tapered cruciform screwdriver had been used, our results may have differed.

We conclude that the auxiliary slotted screw head design modification provided an effective means of back-up extraction of a hexagonal head screw without adversely deforming or weakening screw head integrity. This auxiliary screw head design modification may present useful applications in orthopaedic surgical procedures that routinely rely on hexagonal head cortical screws for internal fixation and that occasionally find the need to remove them (5).

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